**Articles for the search string: "Hypoxia, Dissolved Oxygen, Juvenile or Larval, Fresh Water Fish +"North America."" **
39 possible results.
5/9/2016

Please look at these and let me know which ones you would like. The easiest way to do that would be to highlight the citations in a bright color with Word, resave and send it back to me.

Thanks,

Tanya

Aboagye, D. L. and P. J. Allen (2014). "Metabolic and locomotor responses of juvenile paddlefish Polyodon spathula to hypoxia and temperature." Comparative Biochemistry and Physiology a-Molecular & Integrative Physiology **169**: 51-59.

> Hypoxia is an increasing problem in the natural habitats that the paddlefish (Polyodon spathula) has historically inhabited, and a potential problem in managed culture conditions. However, the effects of hypoxia on paddlefish are not well understood. In order to understand the effects of hypoxia on juvenile paddlefish, acute hypoxia tolerance, aerobic metabolic rates and swimming capabilities were measured under normoxic (PO2 = 140-155 mm Hg) and hypoxic (PO2 = 62-70 mm Hg) conditions at 18 degrees C and 26 degrees C. The results showed that paddlefish acclimated to 18 degrees C and 26 degrees C had routine metabolic rates of 211 mg/kg/h and 294 mg/kg/h, respectively, with a corresponding Q(10) of 1.5. At 18 degrees C and 26 degrees C, paddlefish had a critical partial pressure of oxygen (PO2crit) of 74 mm Hg and 89 mm Hg, respectively. Paddlefish had a lethal oxygen threshold of 31.0 mm Hg and 37.0 mm Hg at 18 C and 26 C, respectively. Further, paddlefish exhibited a reduction in swimming capability when exposed to hypoxia with a 24% and 41% decrease in U-crit at 18 degrees C and 26. degrees C, respectively. Therefore, paddlefish are relatively sensitive to hypoxia, and at temperatures from 18 to 26 degrees C require a dissolved oxygen concentration >= 4.7 mg/L to maintain basal aerobic metabolism and >2.0 mg/L to survive under acute hypoxia. (C) 2013 Elsevier Inc All rights reserved.

Brady, D. C. and T. E. Targett (2013). "Movement of juvenile weakfish Cynoscion regalis and spot Leiostomus xanthurus in relation to diel-cycling hypoxia in an estuarine tidal tributary." Marine Ecology Progress Series **491**: 199-219.

> Fish movement and the spatial and temporal dynamics of hypoxia determine hypoxia exposure and the effect of poor water quality on nursery habitat function. Although water quality criteria for dissolved oxygen (DO) are well defined, hypoxia exposure of juvenile estuary-dependent fishes in situ is largely unknown. Thirty-one juvenile weakfish Cynoscion regalis and spot Leiostomus xanthurus were implanted with acoustic tags. Fish were acclimated for 5 d to either DO saturation or diel-cycling hypoxia (cycling between 11.0 and 2.0 mg O(2)l(-1)). Fish were released during summer into Pepper Creek, Delaware, an estuarine tributary. A logistic

generalized additive model with generalized estimating equations was used to determine which environmental covariates significantly discriminated between movement types. Individual fish tracks were overlain on spatiotemporal contour plots of DO that highlight behavioral avoidance thresholds determined in the laboratory. Most models showed that DO, tide, and the spatial DO gradient were significant predictors of movement. Saturation-acclimated fish generally avoided DO < 2.8 mg O(2)l(-1) by increasing swimming speed and using tidal flow to facilitate escape. An exception to tidally aided movement occurred when a flooding tide appeared to trap smaller fish in spatially extensive hypoxia. Diel-cycling hypoxia acclimated weakfish appeared to have a lower avoidance threshold of similar to 1.4 mg O(2)l(-1). Downstream movements were far more frequent than upstream movements, possibly because late stage juveniles were moving out of the estuary. The relationship between tributary residency and the spatial extent of hypoxia suggests that there is a tradeoff between risk of hypoxic exposure and energetic benefits of remaining in productive areas.

Brandt, S. B., et al. (2009). "Effects of hypoxia on food consumption and growth of juvenile striped bass (Morone saxatilis)." Journal of Experimental Marine Biology and Ecology **381**: S143-S149.

Hypoxia and an apparent temperature-oxygen squeeze have been reported for many coastal ecosystems and reservoirs with striped bass Morone saxatilis. Studies have identified limits of dissolved oxygen (DO) for this species, but interactive effects of concurrent temperatures and low DO have not been addressed. We conducted laboratory experiments on juvenile (23 g) striped bass consumption and growth in a 4x3 factorial design using 4 temperatures (20, 23, 27, and 30 degrees C and 3 DO levels (2 mg L-1, 4 mg L-1 and saturation). Temperature did not affect striped bass food consumption, but consumption increased with increased DO levels. Growth was related to DO as well as to the interaction between temperature and DO, and striped bass growth was strongly curtailed below 4 mg L-1 DO. Laboratory results were used to derive an equation to apply the effects of environmental DO level to striped bass bioenergetics models. Overall results should be useful to predict changes in striped bass habitat quality in response to changes in hypoxic conditions. (C) 2009 Elsevier B.V. All rights reserved.

Breitburg, D. L. (1992). "EPISODIC HYPOXIA IN CHESAPEAKE BAY - INTERACTING EFFECTS OF RECRUITMENT, BEHAVIOR, AND PHYSICAL DISTURBANCE." Ecological Monographs **62**(4): 525-546.

Physical disturbance can be an important force at the individual, population, and community levels of organization. The effects of disturbance may differ for mobile and sessile organisms, however, because of differences in the potential for escape and postdisturbance recolonization by survivors. I used field sampling and laboratory experiments to examine how episodic movement of severely oxygen-depleted (hypoxic) bottom water into nearshore habitat in the Chesapeake Bay affects population density, recruitment, and reproduction of a mobile species-the naked goby (Gobiosoma bosc), a benthic oyster bed fish. Oxygen depletion is a common physical disturbance in freshwater, estuarine, and coastal aquatic systems. In this study, episodic hypoxia influenced mortality, size structure of the population, reproductive behavior, and spatial distribution. Intrusion of severely hypoxic water occurred in late July and early August during the 2-yr study. These intrusions coincided temporally with peak periods of recruitment, and caused the most severe drops in dissolved oxygen concentrations in deep and mid-depth areas of the oyster reef, where recruitment was highest. Laboratory experiments suggested that newly settled recruits require higher oxygen concentrations for survival than do

older individuals. Field samples also indicated that these new recruits are less able to escape to more highly oxygenated shallow water refuges when an intrusion occurs. Thus, the spatial and temporal patterns of recruitment and disturbance, and physiological requirements, combine to result in extremely high mortality of new recruits during severe intrusions. In contrast to effects on new recruits, some large juveniles and adults success fully migrate inshore when oxygen levels decline. In both field samples and laboratory experiments, adult males continued to guard eggs and shelters until dissolved oxygen closely approached lethal levels. Calculations based on size-specific physiological tolerances and swimming speeds suggest that the occurrence of lethal conditions in the fluctuating environment may be more predictable to larger individuals than to new recruits. This predictability may increase the possibility of an appropriate response to low oxygen disturbances by large juveniles and adults. After the disturbance abates, surviving individuals recolonize abandoned areas. This ability of mobile animals to recolonize a disturbed area as adults or juveniles, rather than solely through reproduction, may lead to differences in postdisturbance ecological interactions and differences in selection for colonizing ability between mobile and sessile species.

Breitburg, D. L., et al. (1994). "EFFECTS OF LOW DISSOLVED-OXYGEN ON PREDATION ON ESTUARINE FISH LARVAE." Marine Ecology Progress Series **104**(3): 235-246.

Low dissolved oxygen concentrations, caused by density stratification of the water column and excess nutrient inputs, occur in many aquatic habitats. Laboratory experiments we conducted indicated that low dissolved oxygen has the potential to strongly alter the absolute and relative importance of a suite of estuarine predators of fish larvae. At dissolved oxygen concentrations less than or equal to 2 mg l(-1), predation on naked goby Gobiosoma bosc larvae by an important invertebrate predator of plankton in Chesapeake Bay (the sea nettle scyphomedusa Chrysaora quinquecirrha) increased. In contrast, at the same oxygen concentrations, predation by 2 vertebrate predators, juvenile striped bass Morone saxatilis and adult naked goby, decreased. Changes in consumption of larvae most likely resulted from impaired ability of larvae to escape the scyphomedusa, and decreased attack rates by adult and juvenile fishes. Fish predators increased gill ventilation rates even at oxygen levels higher than those leading to decreased predation. However, we could detect no comparable change in behavior of the sea nettle even at 1 mg l(-1), the lowest oxygen concentration tested. The observed changes in trophic interactions occurred at dissolved oxygen concentrations that are not lethal during short exposures, and that commonly occur in the Chesapeake Bay and other eutrophic estuaries during summer. Thus, low oxygen has the potential to cause significant changes in the importance of alternate trophic pathways in estuarine systems.

Campbell, L. A. and J. A. Rice (2014). "Effects of hypoxia-induced habitat compression on growth of juvenile fish in the Neuse River Estuary, North Carolina, USA." Marine Ecology Progress Series **497**: 199-213.

Hypoxia is thought to have negative effects on fish in coastal ecosystems, but quantifying those effects can be difficult. Direct exposure to hypoxia can reduce fish growth or survival, but fish can also rapidly detect and avoid low dissolved oxygen levels. However, avoidance behavior may result in indirect effects that reduce fish growth. For example, when hypoxic conditions expand, fish densities may increase in nearshore oxygenated refuges, potentially causing density-dependent reductions in growth. We evaluated this hypothesis for juvenile demersal fish species

(primarily spot Leiostomus xanthurus and Atlantic croaker Micropogonias undulatus). By monitoring water quality and fish density across the Neuse River Estuary, North Carolina, USA, under varying water quality conditions during summer 2007, we showed that fish effectively avoided hypoxia despite rapidly changing conditions (minutes to hours), moving away from incursions of hypoxic water and then rapidly redistributing into affected areas after these events passed. Fish densities in nearshore oxygenated refuges increased nearly 2-fold when habitat was compressed by hypoxic waters. Spot in compressed refuges also had significantly less food in their stomachs during June. Based on published estimates of density-dependent spot growth, we estimated that average spot growth rate was reduced 17% during habitat compression events, which occurred 21.5% of the time, translating into an average reduction in growth rate of 4% over the summer. This likely is a conservative estimate of indirect hypoxia effects on growth, as hypoxia was relatively mild in 2007, and density dependence is only one indirect mechanism by which hypoxia may potentially reduce growth.

Cheek, A. O., et al. (2009). "Diel hypoxia in marsh creeks impairs the reproductive capacity of estuarine fish populations." Marine Ecology Progress Series **392**: 211-221.

Seasonal hypoxia in estuaries and continuous hypoxia in the laboratory significantly reduce the reproductive capacity of estuarine fish, but the impacts of diel hypoxia are unknown. This field study quantifies reproductive capacity in populations of gulf killifish (Fundulus grandis) sampled from sites with different dissolved oxygen cycles. Condition factor, gonadosomatic index (GSI), steroid sex hormones, and vitellogenin were measured in F grandis captured in Weeks Bay (WB), Alabama (July 2004 and 2005) and Pensacola Bay (PB), Florida (July 2005). Compared to a control site with little or no diel hypoxia, testes and ovaries were significantly smaller under both moderate (WB: 2.61 mg l(-1), 0.6 h d(-1); PB: 2.41 mg l(-1), 1.5 h d(-1)) and severe (0.93 mg l(-1), 3.4 h d(-1)) diel hypoxia. Male 11-ketotestosterone (11KT) concentrations were significantly lower under moderate hypoxia, while both testosterone (T) and 11KT concentrations were significantly reduced under severe diel hypoxia. In females, T concentrations were similar regardless of the occurrence or severity of hypoxia, but estradiol-17 beta(E2) concentrations were lower under severe diel hypoxia. Since T is unchanged, but its products 11KT and E2 are significantly reduced, hypoxia may affect reproduction by inhibiting specific steroidogenic enzymes in the gonad. The association between diel hypoxia and lower reproductive capacity was consistent across estuaries. Hypoxia-related changes in gulf killifish populations could affect trophic structure in marshes and bays since F. grandis move carbon from the upper marsh surface to the lower marsh, as increased biomass and as prey for juvenile piscivores.

Dabrowski, K., et al. (2004). "Effects of dietary ascorbic acid on oxygen stress (hypoxia or hyperoxia), growth and tissue vitamin concentrations in juvenile rainbow trout (Oncorhynchus mykiss)." Aquaculture **233**(1-4): 383-392.

We examined the effects of three different dietary levels of ascorbic acid (AA) on growth and tissue concentrations in rainbow trout reared in water with three different saturation levels of dissolved oxygen; hypoxia, normoxia, and hyperoxia. Juvenile rainbow trout (initial weight, 1.87 +/- 0.04 g) were distributed into 27 fiberglass, conical tanks with a 3 x 3 factorial design (3 vitamin C levels x 3 dissolved oxygen levels). Three replicate groups of fish (23 fish/tank) were assigned to one of three levels of oxygen and one of three diets containing different levels of

ascorbic acid (10, 100 and 1000 mg AA equivalent/kg diet) designated as marginal, required and high-dose vitamin in the diets, respectively. For the oxygen treatments, hypoxia (50% oxygen saturation), normoxia (100%), and hyperoxia (180%) were set up using systems equipped with oxygen enriching (O(2) injected) or stripping (with N(2)) columns. The growth rates of fish fed experimental diets during 18 weeks are provided and a two-way ANOVA test showed that the growth rates were significantly affected by dissolved oxygen (P<0.001) and dietary ascorbic acids levels (P=0.006). No interaction, however, was found between the parameters (P=0.251). Liver AA concentrations were significantly affected by dietary AA levels (P<0.001), but not by dissolved oxygen level (P=0.142). There was no interaction between the two parameters for liver AA concentration after 18 weeks. Dissolved oxygen and dietary AA levels also significantly affected gill AA concentrations, and an interaction was observed between the two parameters after 18 weeks. Hematocrit values increased and the antioxidant index (ferric reducing ability of plasma, FRAP) decreased with a decrease in oxygen saturation levels. These findings suggest that higher levels of dietary AA have beneficial effects on growth in the hypoxia and normoxia conditions and there seems to be a trend in an increased rate of tissue AA degradation in hyperoxia.

Del Toro-Silva, F. M., et al. (2008). "Influence of oxygen and temperature on growth and metabolic performance of Paralichthys lethostigma (Pleuronectiformes : Paralichthyidae)." Journal of Experimental Marine Biology and Ecology **358**(2): 113-123.

In this study, we apply Fry's classification of environmental factors to demonstrate the limiting effects of oxygen and its interaction with temperature on the growth of juvenile P. lethostigma. We also evaluated the properties of two metabolic indices, marginal metabolic scope (MMS) and limiting oxygen concentration (LOC), as indicators of metabolic scope. We found that oxygen limitation has its greatest impact near the optimum temperature for growth of the species. At 29 degrees C a reduction from 6.00 mg/L to 4.00 mg/L caused a 50% reduction in growth rate while at 27 degrees C the reduction had no significant effect on growth rate. The results are particularly relevant because these temperatures and oxygen concentrations are commonly observed in nursery areas during summer months. At all temperatures fish from the lowest oxygen treatment (1.75 mg/L) had negative growth rates. Comparisons between daily oscillating oxygen treatments and constant treatments failed to demonstrate significant effects. At temperatures past the optimum, growth rates between the 6.00 mg/L and 4.00 mg/L treatments were not statistically different. LOC was significantly affected by temperature, oxygen, and their interaction. Estimates were positively correlated with oxygen treatment (R-2>0.71) and negatively correlated with temperature at moderate and low oxygen concentrations (R-2>-0.84). MMS was significantly affected by temperature and oxygen and was significantly correlated with oxygen treatment (R-2>-0.91), but correlations with temperature were not as clear. In conclusion, oxygen and temperature interactions have significant effects on metabolic scope and growth rates of fish, well above the accepted hypoxia threshold of 2.00 mg/L and MMS has proved a useful estimator of the metabolic scope of the organism within an environment.

Dupont-Prinet, A., et al. (2013). "Impact of hypoxia on the metabolism of Greenland halibut (Reinhardtius hippoglossoides)." Canadian Journal of Fisheries and Aquatic Sciences **70**(3): 461-469.

Greenland halibut (Reinhardtius hippoglossoides), especially juveniles, are frequently found in severely hypoxic areas (18%-25% saturation) of the St. Lawrence Estuary. We investigated the tolerance of this species to hypoxia and evaluated the consequences of low oxygen levels on metabolic capacity. At 5 degrees C, juveniles had a higher critical oxygen threshold than adults (15% versus 11% saturation), indicating that they were less tolerant to hypoxia. Severe hypoxia (19% saturation) did not affect the juveniles' standard metabolic rate but significantly reduced (by 55%) their maximum metabolic rate compared with normoxia. Consequently, the aerobic scope was reduced by 72% in hypoxia compared with normoxia. In juveniles, severe hypoxia increased the duration of digestive processes. The decrease in aerobic scope in hypoxia and the determination of critical oxygen threshold at a saturation level close to actual field dissolved oxygen values strongly suggest that juveniles from the St. Lawrence Estuary are living at the edge of their metabolic capacity. Consequently, the growth and distribution of Greenland halibut could be affected if there are further declines in dissolved oxygen availability.

Eby, L. A., et al. (2005). "Habitat degradation from intermittent hypoxia: impacts on demersal fishes." Marine Ecology Progress Series **291**: 249-261.

As eutrophication of estuaries and coastal oceans increases worldwide, the resulting expansion of hypoxic zones represents an increasingly frequent form of habitat degradation. Although impacts of prolonged hypoxia on benthic invertebrate species are well-documented, there is little understanding of how those effects subsequently influence the motile upper trophic levels in estuarine ecosystems. Quantitative nekton surveys in the Neuse River Estuary and field experiments in June and August 1999 using Atlantic croaker Micropogonias undulatus demonstrated that intermittent hypoxia decreased habitat quality for juvenile, demersal fish through 3 pathways: (1) hypoxia restricted the fishes in estuaries to shallow, oxygenated areas, where in the early part of the summer about 1/3 fewer prey resources were available. (2) This contraction of suitable habitat crowded the fish into smaller areas and may have resulted in density-dependent reduction of growth rates. (3) Most importantly, mortality of sessile infauna in deeper areas exposed to intermittent hypoxia decreased prey densities about 8-fold between the June and August experiments. Through these mechanisms, intermittent hypoxia may result in ecological crunches or bottlenecks. Field data collected from May to October in 3 yr (1998 to 2000) with differing levels of hypoxia support the conclusion that intermittent hypoxia may decrease habitat quality and result in >= 50% declines in juvenile fish growth rate. Incorporation of these indirect effects of hypoxia on juvenile growth rates into a population model demonstrated the potential for significant (similar to 4%) reductions in population growth rate. Thus, sublethal effects of hypoxia-driven habitat degradation may impact fisheries production not only through reduced size at age, but also through reduced abundance of demersal fish populations.

Eerkes-Medrano, D., et al. (2013). "Contrasting effects of hypoxic conditions on survivorship of planktonic larvae of rocky intertidal invertebrates." Marine Ecology Progress Series **478**: 139-+.

Hypoxia is increasing in coastal zones worldwide, with acute effects on demersal fish and benthic invertebrate communities in shallow coastal and estuarine habitats. Less studied are the effects of hypoxia on planktonic larvae of open coastal habitats. Climate change projections suggest intensified hypoxia in open coast upwelling systems, such as the northern California Current Upwelling System, where there has been a recent rise of seasonally persistent inner-

shelf hypoxia (dissolved oxygen [DO] < 1.43 ml l(-1)) and anoxia (DO 0 ml l(-1)). We examined survivorship of larval invertebrates exposed to low oxygen conditions in controlled laboratory experiments. Multiple-day hypoxic conditions, resembling DO levels in nearshore Oregon waters, were gene rated by bubbling seawater with nitrogen gas. Tolerance levels among species varied, from larvae of species with little tolerance to hypoxia (e. g. the shore crab Hemigrapsus oregonensis) to species with high tolerance (e. g. the California mussel Mytilus californianus). These contrasting responses among open-coast intertidal taxa suggest that chronic hypoxia or anoxia may have different effects on recruitment success among species and, consequently, on the structure and species composition of open coast intertidal communities.

Gaston, G. R., et al. (1985). "THE EFFECTS OF HYPOXIA AND BRINE ON RECOLONIZATION BY MACROBENTHOS OFF CAMERON, LOUISIANA (USA)." Contributions in Marine Science **28**: 79-93.

Gaulke, G. L., et al. (2015). "Behavioral and Physiological Responses of Largemouth Bass to Rain-Induced Reductions in Dissolved Oxygen in an Urban System." Transactions of the American Fisheries Society **144**(5): 927-941.

Waters in urban areas often experience hypoxic events due to combined sewer overflows, which have the potential to negatively affect aquatic biota. Despite these hypoxic events, many urban areas have diverse fish assemblages, suggesting hypoxia has a minimal impact. Data to quantify the impacts of aquatic hypoxia in urban systems are currently lacking. The current study sought to define how rain-induced hypoxia affected the movement, distribution, and physiology of individual Largemouth Bass Micropterus salmoides residing in the Chicago Area Waterway System (CAWS), an urban area prone to episodes of hypoxia. Following the onset of hypoxic events, the likelihood of Largemouth Bass remaining in hypoxic water was reduced, but fish did not completely avoid hypoxic areas. This suggests that hypoxia exerts only a moderate influence on the movement of Largemouth Bass. Field sampling showed that Largemouth Bass from the site prone to hypoxia were not in poor nutritional condition and were not suffering from chronic stress, relative to compared with those from reference sites. Field sampling also showed that fish from the CAWS displayed an improved capability to transport oxygen in the blood compared with individuals from control sites. Following a low-oxygen challenge in the laboratory, fish from the CAWS also displayed elevated levels of oxygen transport capabilities compared with fish from some control sites. Together, results suggest that hypoxic events have limited behavioral consequences for Largemouth Bass, and in fact, Largemouth Bass in our study may have developed an improved ability to tolerate hypoxia, which would allow them to persist in hypoxia-prone areas.

Geiger, S. P., et al. (2000). "Air breathing and gill ventilation frequencies in juvenile tarpon, Megalops atlanticus: Responses to changes in dissolved oxygen, temperature, hydrogen sulfide, and pH." Environmental Biology of Fishes **59**(2): 181-190.

This study quantified the air-breathing frequency (ABf in breaths h(-1)) and gill ventilation frequency (Vf in ventilations min(-1)) of tarpon Megalops atlanticus as a function of PO2, temperature, pH, and sulphide concentration. Ten tarpon held at normoxia at 22-33 degrees C without access to atmospheric oxygen survived for eight days, and seven survived for 14 days (at which point the experiment was terminated) suggesting that the species is a facultative, rather than an obligate, air breather. At temperatures of 29 degrees C and below ABf was highest and

Vf was lowest at low oxygen partial pressures. Tarpon appear to switch from aquatic respiration to air breathing at PO2 levels of roughly 40 torr. The gills were the primary organ for oxygen uptake in normoxia, and the air-breathing organ the primary mechanism for oxygen uptake in hypoxia. At 33 degrees C, both ABf and Vf were elevated but highly variable, regardless of PO2. There were no mortalities in tarpon exposed to total H2S concentrations of 0-232 mu M (0-150.9 mu M H2S); however, high sulfide concentrations resulted in very high ABf and Vf near zero. Vf was reduced when pH was acidic. We conclude that air breathing provides an effective means of coping with the environmental conditions that characterize the eutrophic ponds and sloughs that juvenile tarpon typically inhabit.

Goodman, L. R. and J. G. Campbell (2007). "Lethal levels of hypoxia for gulf coast estuarine animals." Marine Biology **152**(1): 37-42.

There is increasing concern about eutrophication and subsequent hypoxia problems in estuaries. The US Environmental Protection Agency has developed Water Quality Criteria (WQC) for dissolved oxygen (DO) in saltwater for Cape Cod, MA to Cape Hatteras, NC but inadequate data exists for development of such criteria for other coastal geographic areas. We performed acute tests with two species of crustaceans and seven species of estuarine fishes native to the Gulf of Mexico to complement the data base for northeastern species. Flow-through tests were conducted for either 24- or 48-h at test temperatures from 24 to 28 degrees C and at salinities from 20 to 31.5 parts per thousand. Estimated 24- h LC50 values obtained for crustaceans ranged from 1.36 mg/l for adult pink shrimp to 1.56 mg/l for 10-day-old mysids. Similarly, estimated LC50 values for fish ranged from 1.34 mg/l in one of the three tests with pinfish to 2.22 mg/l in one of the two tests with scaled sardines. The majority of mortality attributable to low DO concentrations in our experiments usually occurred within the first 4 h of exposure. LC50 values for the species tested are below the WQC recommended protective limit of 2.3 mg/l for juvenile and adult animals.

Hasler, C. T., et al. (2009). "The Influence of Dissolved Oxygen on Winter Habitat Selection by Largemouth Bass: An Integration of Field Biotelemetry Studies and Laboratory Experiments." Physiological and Biochemical Zoology **82**(2): 143-152.

In this study, field biotelemetry and laboratory physiology approaches were coupled to allow understanding of the behavioral and physiological responses of fish to winter hypoxia. The biotelemetry study compared dissolved oxygen levels measured throughout the winter period with continually tracked locations of nine adult largemouth bass obtained from a whole-lake submerged telemetry array. Fish habitat usage was compared with habitat availability to assess whether fish were selecting for specific dissolved oxygen concentrations. The laboratory study examined behavioral and physiological responses to progressive hypoxia in juvenile largemouth bass acclimated to winter temperatures. Results from the dissolved oxygen measurements made during the biotelemetry study showed high variance in under-ice dissolved oxygen levels. Avoidance of water with dissolved oxygen <2.0 mg/L by telemetered fish was demonstrated, but significant use of water with intermediate dissolved oxygen levels was also found. Results from the lab experiments showed marked changes in behavior (i.e., yawning and vertical movement) at <2.0 mg/L of dissolved oxygen but no change in tissue lactate, an indicator of anaerobic metabolism. Combined results of the biotelemetry and laboratory studies demonstrate that a dissolved oxygen content of 2.0 mg/L may be a critical threshold that induces behavioral

responses by largemouth bass during the winter. In addition, the use by fish of areas with intermediate levels of dissolved oxygen suggests that there are multiple environmental factors influencing winter behavior.

Hoffman, J. C., et al. (2008). "Overwintering habitats of migratory juvenile American shad in Chesapeake Bay." Environmental Biology of Fishes **81**(3): 329-345.

We describe overwintering habitats of age-0 American shad in the lower Chesapeake Bay estuary through analyses of multiple, complementary data sets, including bottom-trawls of the Virginia portion of Chesapeake Bay and its tributaries, stable isotope analysis of American shad and common prey items, and stomach content analysis. This is the first detailed description of overwintering habitats used by young American shad during their first migration to the Atlantic Ocean. American shad generally migrated from their freshwater rearing habitat during November and December and migrated to the ocean during February through March. American shad were captured in all of Virginia's tributaries and along Chesapeake Bay's western coast. These fish were caught in relatively cool waters (5-9 degrees C) over a wide range of salinities (0.1-27.5). Strong selection for certain temperatures or salinities was not apparent. Stomach content and stable isotope analyses demonstrated that juveniles were feeding in the estuary, growing on a diet of estuarine calanoid copepods, mysid shrimps, and larval fishes. The stable isotope data were used to describe temperature- and size-cued migration from fresh water. Temperature was an important cue affecting both the timing and the rate of migration. Further, American shad exhibited at least three different size-related migration behaviors: most juveniles emigrated from the freshwater rearing habitat at 2-5 g (ca. 55-75 mm fork length); other juveniles emigrated at a size of 2 g or less and rapidly moved into the lower estuary; and finally, a few juveniles remained in the upper estuary and did not emigrate until they were 5 g or larger. A few American shad were captured with anomalous stable isotope signatures, which may be explained by migration into the Chesapeake Bay estuary from an adjacent system.We describe overwintering habitats of age-0 American shad in the lower Chesapeake Bay estuary through analyses of multiple, complementary data sets, including bottom-trawls of the Virginia portion of Chesapeake Bay and its tributaries, stable isotope analysis of American shad and common prey items, and stomach content analysis. This is the first detailed description of overwintering habitats used by young American shad during their first migration to the Atlantic Ocean. American shad generally migrated from their freshwater rearing habitat during November and December and migrated to the ocean during February through March. American shad were captured in all of Virginia's tributaries and along Chesapeake Bay's western coast. These fish were caught in relatively cool waters (5-9 degrees C) over a wide range of salinities (0.1-27.5). Strong selection for certain temperatures or salinities was not apparent. Stomach content and stable isotope analyses demonstrated that juveniles were feeding in the estuary, growing on a diet of estuarine calanoid copepods, mysid shrimps, and larval fishes. The stable isotope data were used to describe temperature- and size-cued migration from fresh water. Temperature was an important cue affecting both the timing and the rate of migration. Further, American shad exhibited at least three different size-related migration behaviors: most juveniles emigrated from the freshwater rearing habitat at 2-5 g (ca. 55-75 mm fork length); other juveniles emigrated at a size of 2 g or less and rapidly moved into the lower estuary; and finally, a few juveniles remained in the upper estuary and did not emigrate until they were 5 g or larger. A few American shad were captured with anomalous stable isotope signaturs, which may be explained by migration into the Chesapeake Bay estuary from an adjacent system.

Hypes, S. R. and P. L. Defur (1998). "Effects of hypoxia/hypercapnia on Callinectes sapidus in the York River, VA." American Zoologist **38**(5): 197A-197A.

Johannessen, D. I. and P. S. Ross (2002). "Late-run sockeye at risk: an overview of environmental contaminants in Fraser River salmon habitat." Canadian Technical Report of Fisheries and Aquatic Sciences **2429**: i-x, 1-108.

Fraser River sockeye salmon (Oncorhynchus nerka) utilize some of the most populated and industrialized regions of British Columbia during sensitive life stages (e.g. spawning, egg hatching, larval development and migrations between fresh and salt water). During the period from 1994 to 2001, pre-spawning mortality of adults, associated with a change in migration timing, increased from 10% to over 90% among late-run stocks of Fraser River sockeye. It is estimated that this level of mortality could translate to lost production/harvest of approximately 5 million fish with an approximate value of $50 million dollars in 2002 alone. A contaminant-associated impact represents one of several possible contributing factors touted in the sudden appearance of this mysterious phenomenon. Contaminants could be contributing to the disruption of migratory timing through a number of contaminant-related impacts, including a disruption of endocrine processes (e.g. permanent or transitory neurotoxicity or developmental toxicities) or interference with olfactory cues during migration. In this literature-based risk assessment, we review contaminant types, usage, and sources in late-run sockeye habitat, and prioritize contaminants of concern. Contaminants were prioritized based on whether there was evidence of increasing use, or sale, of the contaminant in sockeye habitat during the period in question. Where known, toxicity, sublethal effects, and other factors are also discussed. Based on this assessment, we conclude that there is a need for research into the exposure levels and effects of several key chemical classes of concern including: i) two classes of persistent organic pollutants (POPs): polybrominated diphenylethers (PBDEs) and phthalate esters; ii) the family of organic surfactants including alkylphenol ethoxylates (APEs) and their degradation products; iii) a number of agricultural and household pesticides which have seen increased use in B.C. during the 1990s, including metam sodium, formaldehyde, and chlorothalonil; and iv) the wood preservatives creosote, chromated copper arsenate, ammoniacal copper arsenate, and ammoniacal copper zinc arsenate. Also of concern are a number of contaminants for which almost no information exists, but are likely to be increasing in the environment, including pharmaceutical and personal care product chemicals, which enter waterways through sewage effluent. The lack of data on the concentrations of any of these contaminants in Fraser River late-run sockeye salmon stocks render it impossible to accurately assess the possible role of contaminants in the disruption of migratory timing in late-run sockeye stocks. However, our assessment does provide a listing of several contaminant classes of concern, and highlights the need for scientific research which i) characterizes contaminant types and concentrations in late-run sockeye, and ii) evaluates the toxicity of different priority chemicals to different stages of sockeye salmon.

Levy, D. A., et al. (1990). "IMPACTS OF LOG STORAGE UPON EPILIMNETIC DISSOLVED-OXYGEN AND JUVENILE SOCKEYE-SALMON IN BABINE LAKE, BRITISH-COLUMBIA." Water Research **24**(3): 337-343.

McNatt, R. A. and J. A. Rice (2004). "Hypoxia-induced growth rate reduction in two juvenile estuary-dependent fishes." Journal of Experimental Marine Biology and Ecology **311**(1): 147-156.

As eutrophication of coastal waters increases, water quality issues such as hypoxia have come to the forefront of environmental concerns for many estuarine systems. Chronic hypoxia during the summer has become a common occurrence in numerous estuaries, degrading nursery habitat and increasing the potential for exposure of juvenile fish to low levels of dissolved oxygen (DO). We conducted a laboratory study to investigate how hypoxic conditions and temperature affect growth rates of two juvenile estuary-dependent fish: the Atlantic menhaden (Brevoortia tyrannus) and spot (Leiostomus xanthurus). For a 2-week period, we exposed the fish to one of four constant DO levels (6.0, 4.0, 2.0 or 1.5 mg O-2 1(-1)), at one of two temperatures (25 or 30 degreesC). A fifth DO treatment, included for spot at 30 degreesC, allowed DO to fluctuate from 10.0 mg O-2 1(-1) during the day, to 2.0 mg O-2 1(-1) at night. This diel fluctuation approximated the natural DO cycle in tidal estuarine creeks. Size measurements were recorded at the beginning, middle and end of experiments. Growth rates were generally unaffected by low DO until concentrations dropped to 1.5 Mg O-2 1(-1), resulting in 31-89% growth reductions. Our results suggest that DO levels must be severely depressed, and in fact, approaching lethal limits, to negatively impact growth of juvenile spot and Atlantic menhaden. Published by Elsevier B.V.

Miller, D. C., et al. (2002). "Determination of lethal dissolved oxygen levels for selected marine and estuarine fishes, crustaceans, and a bivalve." Marine Biology **140**(2): 287-296.

The objective of this study was to provide a database of the incipient lethal concentrations for reduced dissolved oxygen (DO) for selected marine and estuarine species including 12 species of fish, 9 crustaceans, and I bivalve. All species occur in the Virginian Province, USA, which is a cold temperate region. The study period was August 1987 to September 1995. Standard bioassay procedures were employed, with most tests being of 4-day duration. Up to eight lethal concentrations (LCs) between LC05 and LC95 were estimated. The study provides four general conclusions about determining lethal thresholds of low DO for these organisms. First, the concentration response curve of most species did not change greatly beyond day I of the exposure with the exception of crustacean larvae, which were usually more sensitive on day 4, possibly due to molting. Second, acute LC50 values (1- to 4-day) for low DO were influenced by life-stage and. habitat, with pelagic larvae generally being the most sensitive and benthic juveniles the least. Species mean LC50 values ranged from 1.4 to 3.3 mg l(-1) for larvae, 1.0 to 2.2 mg l(-1) for postlarvae, and 0.5 to 1.6 mg l(1) for juveniles. No intraspecific differences in LC50 were detected between larval stages in crustaceans or with age in larval fishes. The response range between LC05 and LC95 was narrowest for the least sensitive organisms (0.6 mg l(-1)), and broadened with sensitivity. The mean LC10:LC50 ratio for all species was 1.32 for larvae and juveniles, and 1.36 for postlarvae. The ratio for postlarvae represents only four species, and hence is not considered different from the other life stages. Third, variability increased with increased species and life stage sensitivity to low DO, and with endpoints of LC15 and below, which reduces the certainty of some of these results. Lastly, no influence of temperatures between 20degreesC and 30degreesC was detected in a small set of tests with thermally acclimated crustacean larvae. This data set has been used to describe protection limits for juvenile and adult survival, and for larval recruitment for the case of persistent (greater than or equal to24 h) low DO for estuarine and coastal waters of the Virginian Province, USA.

Niklitschek, E. J. and D. H. Secor (2009). "Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: I. Laboratory results." Journal of Experimental Marine Biology and Ecology **381**: S150-S160.

Dissolved oxygen and salinity are relevant structuring factors which should be incorporated into habitat and bioenergetic models for estuarine fishes. We measured growth, food consumption, routine and postprandial metabolism, egestion and survival responses of juvenile Atlantic sturgeon (young-of-the-year: YOY, 6-48 g) in an incomplete factorial array of temperature, salinity and dissolved oxygen levels. Complementary measures were also conducted on yearlings (11 year-old, 70-300 g) to evaluate size and age effects upon food consumption and growth. All three factors had a significant effect on major bioenergetic responses, as well as several of their first order interactions. Maximum growth and food consumption rates were observed above 70% dissolved oxygen saturation, at 20 degrees C, and between salinities of 8 and 15. Postprandial metabolism was reduced and egestion increased under hypoxia (50% DO saturation), suggesting compensatory mechanisms aimed to reduce assimilation rates. A significant shift in growth responses with age indicated higher tolerance to salinity in yearlings than in YOY. No other size dependent changes were significant, either for hypoxia or for temperature effects. Survival tended to increase with dissolved oxygen saturation, and decreased at the highest temperature and salinity levels. Our results indicated both additive and synergistic effects of tested environmental factors upon ecophysiological responses and highlighted the need to consider these in new bioenergetic models. (C) 2009 Elsevier B.V. All rights reserved.

Ripley, J. L. and C. M. Foran (2007). "Influence of estuarine hypoxia on feeding and sound production by two sympatric pipefish species (Syngnathidae)." Marine Environmental Research **63**(4): 350-367.

This research utilizes the acoustic behavior of two sympatric pipefish species to assess the impact of hypoxia on feeding, We collected northern, Syngnathus fuscus, and dusky pipefishes, Syngnathus floridae, from the relatively pristine Chincoteague Bay, Virginia, USA and audiovisually recorded behavior in the laboratory of fish held in normoxic (>5 mg/L O-2) and hypoxic (2 and 1 mg/L O-2) conditions. Both species produced high frequency (similar to 0.9-1.4 kHz), short duration (3-22msec) clicks. Feeding strikes were significantly correlated with both wet weight of ingested food and click production. Thus, sound production serves as an accurate measure of feeding activity. In hypoxic conditions, reduced food intake corresponded with decreased sound production. Significant declines in both behaviors were evident after I day and continued as long as hypoxic conditions were maintained. Interspecific differences in sensitivity were detected. Specifically, S. floridae showed a tendency to perform head snaps at the surface. S. fuscus exhibited a breakdown in the coupling of sound production with food intake in 2mg/L O-2 with clicks produced in other contexts, particularly choking and food expulsion. Reductions in feeding will ultimately impact growth, health, and eventually reproduction as resources are devoted to survival instead of gamete production and courtship. This work suggests acoustic monitoring of field sites with adverse environmental conditions may reflect changes in feeding behavior in addition to population dispersal. (c) 2006 Elsevier Ltd. All rights reserved.

Ruggerone, G. T. (2000). "Differential survival of juvenile sockeye and coho salmon exposed to low dissolved oxygen during winter." Journal of Fish Biology **56**(4): 1013-1016.

Juvenile sockeye salmon (43-78 mm) survived 100% for 24 h in cages in ice-covered Black Lake, Alaska at oxygen saturations >65% (9 mg l(-1)), but only 45% at 24% saturation (3.0-3.3 mg l(-1)) and none at <17% saturation (2.3 mg l(-1)). All juvenile coho (50-120 mm) survived 100% for 24 h down to 21% oxygen saturation (3.1 mg l(-1)), and all 50 coho survived 4-5 days at 23-24% saturation (3.2-3.3 mg l(-1)). (C) 2000 The Fisheries Society of the British Isles.

Sagasti, A., et al. (2001). "Effects of periodic hypoxia on mortality, feeding and predation in an estuarine epifaunal community." Journal of Experimental Marine Biology and Ecology **258**(2): 257-283.

The York River Estuary, a tributary of the Chesapeake Bay, USA, experiences periodic low oxygen stress (hypoxia), yet epifaunal species form dense communities there. We studied hypoxia tolerance of common epifaunal species in the York River by exposing sessile and mobile epifauna to high and low oxygen concentrations in laboratory aquaria. Mortality in hypoxia varied among species, ranging from 0% to 100%, with trends of decreased tolerance by mobile species relative to sessile species. While most species tested experienced some mortality after being exposed to hypoxia (at 1 mg O-2/l or 0.5 mg O-2/l) for 5 days, many species had a median lethal time (LT50) in hypoxia greater than 1 week (3 of 6 species at 1 mg O-2/l and 6 of 14 species at 0.5 mg O-2/l), the maximum duration of typical hypoxic episodes in the York River, suggesting that hypoxia may cause little mortality for some species in this system. However. hypoxia had sub-lethal effects on behavior in all species tested. Epifaunal animals responded to hypoxia with behaviors that moved them higher in the water column or by entering resting states until hypoxia passed. Feeding and predation by a variety of tars (the hydroid Obelia bicuspidata, the mud crab Neopanope sayi, juvenile blue crabs Callinectes sapidus, the flatworm Stylochus ellipticus, and the nudibranch Doridella leucolena) decreased during hypoxia, despite varying mortality responses to low oxygen stress, suggesting that short hypoxic episodes may create predation refuges for prey species. At least one highly tolerant species (O. bicuspidata) showed substantially decreased growth in hypoxia. Although relatively high tolerance of hypoxia by many estuarine epifaunal species limits serious disturbance during brief hypoxic episodes. hypoxia's greatest impact on York River epifaunal communities might be through its indirect effects on behavior and predation.

Schlenger, A. J., et al. (2013). "Modeling the influence of hypoxia on the potential habitat of Atlantic sturgeon Acipenser oxyrinchus: a comparison of two methods." Marine Ecology Progress Series **483**: 257-272.

Management of marine and estuarine fish and shellfish would benefit from a numerical approach that quantifies the impacts of climate variability and eutrophication. We present a proof-of-concept habitat volume model that incorporates predictions from a 3-dimensional biophysical model. Using temperature, salinity, and dissolved oxygen, habitat volumes were calculated based on threshold physiological tolerances (fixed criteria) and potential growth (bioenergetics) for Atlantic sturgeon Acipenser oxyrinchus. Simulations from a coupled oxygen and hydrodynamic model of the Chesapeake Bay, USA, were used to estimate habitat volumes of juvenile sturgeon and assess the sensitivity of habitat to environmental factors. In winter, salinity controlled the required (needed for survival) and optimal (needed for highest growth) habitat. Temperature and salinity defined spring and autumn optimal habitat, and a combination of salinity, temperature and dissolved oxygen influenced habitat volumes during summer. Although average summertime oxygen limitation reduced the volumes of juvenile

habitat by 3.3-28.0%, the largest reductions in summertime habitat resulted from temperature limitation. The average difference in annual and seasonal volumes between fixed-criteria and bioenergetics methods was approximately 14%, with similar trends over the annual cycle for most life stages and habitat types. We conclude that fixed-criteria habitat volume models would be suitable when bioenergetics information is not available. Both habitat volume models can be used to assess the impacts of climate change and eutrophication on the habitat of fish and shellfish in regions where hydrodynamic models exist and for species for which physiological tolerances are known.

Shimps, E. L., et al. (2005). "Hypoxia tolerance in two juvenile estuary-dependent fishes." Journal of Experimental Marine Biology and Ecology **325**(2): 146-162.

Hypoxia events, or low dissolved oxygen (DO) conditions, occur frequently in North Carolina estuaries during the Summer. These events may have harmful effects on important fish stocks, including spot (Leiostomus xanthurus) and Atlantic menhaden (Brevoortia tyrannus), but their consequences are not well understood. We investigated direct mortality due to hypoxia in juvenile spot and Atlantic menhaden to determine how the extent of mortality varies with the severity of hypoxia and the duration of exposure, and to explore how vulnerability to hypoxia changes across species, fish size, and temperature. Atlantic menhaden and spot were tested at two temperatures, 25 and 30 T, and three dissolved oxygen concentrations, 0.6, 0.9, and 1.2 ppm. Survival analyses were performed oil the data relating survival rate of each species to dissolved oxygen concentration, duration of exposure, fish size, and temperature. The data were analyzed using an LC50 approach for comparative purposes, and 12h LC50 estimates ranged from 0.9 to 1.1 ppm O-2. Spot and menhaden exposed to 1.2 ppm O-2, showed no mortality in 24 h at 25 degrees C, and only 30-40% mortality at 30 T. In contrast, both species experienced 100% mortality in 2-6 h at 0.6 ppm O-2, There was an effect of size on hypoxia tolerance, with small spot being less tolerant than large spot, while the converse size effect was observed for menhaden. Spot were consistently less tolerant to hypoxia than menhaden and both species were less tolerant to hypoxia at 30 T than at 25 T. Preliminary experiments showed a 24-h acclimation to sublethal levels of hypoxia significantly reduced mortality upon subsequent exposure to lethal hypoxia concentrations. Our results indicate that direct mortality due to hypoxia will vary with species, size, and temperature, but will likely only be substantial when these species are exposed to oxygen concentrations less than about 1 ppm O-2, Given the severity of hypoxia necessary to cause mortality and the ability of fish to behaviorally avoid hypoxia, direct mortality due to hypoxia may have limited impacts on fish population dynamics. Therefore, the greatest effects due to hypoxia may be Caused by the stress imposed by sublethal hypoxic conditions alone or in concert with other stressors, or by indirect effects incurred by avoiding hypoxic areas.

Snyder, S., et al. (2016). "Effect of closed v. intermittent-flow respirometry on hypoxia tolerance in the shiner perch Cymatogaster aggregata." Journal of Fish Biology **88**(1): 252-264.

This study compares the critical oxygen saturation (O-2crit) levels of the shiner perch Cymatogaster aggregata obtained using two different methods wherein hypoxia is induced either by the fish's respiration (closed respirometry) or by degassing oxygen with nitrogen (intermittent-flow respirometry). Fish exhibited loss of equilibrium at a higher O-2 saturation in the closed respirometry method when compared with the intermittent-flow method. Utilization

of closed respirometry yielded O-2crit measurements that were almost twice as high as those obtained with intermittent-flow respirometry. The lower hypoxia tolerance in closed respirometry is consistent with additional stress, caused by a build-up of ammonia and carbon dioxide and a faster rate in dissolved oxygen decline. The results indicate that these two methods of determining hypoxia tolerance in aquatic organisms are not comparable, and that much care should be given to method choice.

Sparks, B. L. and D. L. Strayer (1998). "Effects of low dissolved oxygen on juvenile Elliptio complanata (Bivalvia : Unionidae)." Journal of the North American Benthological Society **17**(1): 129-134.

Through use of a closed, circulating system, we examined the effects of low oxygen on the behavior and survival of juvenile Elliptio complanata, a common freshwater clam. Clams exposed to low oxygen exhibited increased stress behavior, extending their siphons, gaping, and surfacing more often than clams exposed to higher concentrations of oxygen. Stress levels rose with exposure time and led to increased mortality in a long-term study. Low oxygen in sediments may limit juvenile survival through direct mortality and indirectly through behaviors that can lead to increased mortality. Knowledge of the limitations may prove useful in clam reestablishment programs and for regulation of management practices near existing clam beds.

Stierhoff, K. L., et al. (2006). "Ecophysiological responses of juvenile summer and winter flounder to hypoxia: experimental and modeling analyses of effects on estuarine nursery quality." Marine Ecology Progress Series **325**: 255-266.

Growth and feeding rates were measured in juvenile summer flounder Paralichthys dentatus and winter flounder Pseudopleuronectes americanus exposed to sub-lethal hypoxia (low dissolved oxygen, DO) over a range of temperatures, to determine its potential effects on nursery habitat quality for these 2 estuary- dependent flatfishes. Growth rates of both species were generally reduced as DO decreased, particularly at DO levels of 50 to 70 % air saturation, and as temperature increased. Summer flounder were more tolerant of low DO than were winter flounder at both 20 and 25 degrees C. At these temperatures, summer flounder growth was reduced by similar to 25 % (compared to growth at normoxia [7.0 Mg O-2 l(-1)) at 3.5 mg O-2 l(-1) and by 50 to 60% at 2.0 mg O-2 l(-1)- In contrast, growth of winter flounder at 20 degrees C was reduced by similar to 50% at both 3.5 and 5.0 Mg O-2 l(-1), and growth was zero at 2.0 Mg O-2 l(-1). At 25 degrees C, winter flounder grew poorly in all DO treatments and lost weight at 2.0 Mg O-2 l(-1). Summer flounder were also tested at 30 degrees C. Growth was significantly reduced even at 5.0 mg O-2 l(-1), and was reduced by similar to 90 % at 2.0 Mg O-2 l(-1). A significant relationship between feeding rate and growth suggested reduced consumption to be a major cause of growth limitation under hypoxia. There was no evidence of growth acclimation for either species after 7 to 14 d exposure to hypoxia. The effect of hypoxia on growth of summer flounder was reduced at lower salinity (15 vs. 25%.) and was unaffected by the presence of a sand substrate. Similarity between modeled growth under hypoxic conditions, based on our laboratory results, and observed growth of summer flounder in a hypoxic estuarine tributary suggests growth limitation in the wild. These laboratory and field results demonstrate that even moderate hypoxia can adversely affect growth rates, and thus the quality of estuarine nursery habitats for juvenile flatfishes.

Stierhoff, K. L., et al. (2009). "Hypoxia-induced growth limitation of juvenile fishes in an estuarine nursery: assessment of small-scale temporal dynamics using RNA:DNA." Canadian Journal of Fisheries and Aquatic Sciences **66**(7): 1033-1047.

The ratio of RNA to DNA (RNA:DNA) in white muscle tissue of juvenile summer flounder (Paralichthys dentatus) and weakfish (Cynoscion regalis) was used as a proxy for recent growth rate in an estuarine nursery. Variability in RNA:DNA was examined relative to temporal changes in temperature and dissolved oxygen (DO). Initial laboratory experiments indicated (i) a strong positive relationship between RNA:DNA and growth rate, (ii) a rapid response of RNA:DNA to changes in feeding, and (iii) no effect of hypoxia on the relationship between RNA:DNA and growth rate (tested in weakfish only). Diel cycling DO occurred in the nursery throughout the summers of 2002 and 2003. Canonical correlation analysis of field data indicated a strong positive relationship between RNA:DNA and mean DO conditions prior to capture in both species. Correlations were weak or insignificant between stomach content mass (an index of feeding) and mean DO and between RNA:DNA and stomach content mass and DO variability. These results suggest a strong functional relationship between DO concentration and the growth rate of juvenile fishes in an estuarine nursery. Furthermore, growth rates of wild-caught fishes (estimated from RNA:DNA) appear to be more negatively impacted by diel cycling hypoxia than would be expected from published laboratory data.

Suthers, I. M. and J. H. Gee (1986). "ROLE OF HYPOXIA IN LIMITING DIEL SPRING AND SUMMER DISTRIBUTION OF JUVENILE YELLOW PERCH (PERCA-FLAVESCENS) IN A PRAIRIE MARSH." Canadian Journal of Fisheries and Aquatic Sciences **43**(8): 1562-1570.

Switzer, T. S., et al. (2015). "Habitat Use by Juvenile Red Snapper in the Northern Gulf of Mexico: Ontogeny, Seasonality, and the Effects of Hypoxia." Transactions of the American Fisheries Society **144**(2): 300-314.

Red Snapper Lutjanus campechanus in the northern Gulf of Mexico are threatened by the combined influence of fishing pressures, the bycatch of juveniles in the shrimp trawl fishery, and the seasonal formation of hypoxic (<= 2 mg/L O-2) bottom water along the Louisiana-Texas continental shelf. Juveniles are especially at risk from hypoxia because they leave the plankton and transition from pelagic to demersal habitats en masse during summer, when hypoxic conditions peak. We explored the influence of hypoxia on juvenile Red Snapper by examining habitat suitability during years with low (areal extent, <10,000 km(2)), moderate (10,000-19,999 km(2)), and severe (>= 20,000 km(2)) hypoxia through retrospective analyses of groundfish data from the Southeast Area Monitoring and Assessment Program. Significant interannual variability in the strength of juvenile recruitment was evident, and in general the weakest recruitment was observed during years of severe hypoxia. The relative abundance of juveniles in shallow (9-46 m) waters off central Louisiana was significantly reduced during years of severe hypoxia; this reduction was generally accompanied by an increase in relative abundance of Red Snapper longitudinally and in deeper waters. Patterns of habitat use during summer months varied in relation to hypoxia severity, with individuals occupying sites that were deeper, colder, and of higher salinity during years of severe hypoxia. Red Snapper also exhibited ontogenetic habitat shifts into deeper, cooler, and higher-salinity waters as fish size increased. In general, Red Snapper populations appear resilient to the broad-scale effects of severe hypoxia, although

more localized effects may be in force but not evident because of the many factors affecting survival.

Taylor, J. C. and J. M. Miller (2001). "Physiological performance of juvenile southern flounder, Paralichthys lethostigma (Jordan and Gilbert, 1884), in chronic and episodic hypoxia." Journal of Experimental Marine Biology and Ecology **258**(2): 195-214.

Dissolved oxygen (DO) is proving to be one of the most important abiotic factors determining growth and survival of juvenile estuarine fish. In shallow, throughout estuarine systems, low DO can occur in two broad categories: a diel oscillating pattern resulting in repeated nocturnal hypoxia due to the photosynthesis-respiration cycle of algal populations, or as prolonged bottom water hypoxia or anoxia caused by stratification. A series of laboratory experiments was conducted to characterize the physiological performance of juvenile southern flounder, Paralichthys lethostigma, (55-65 mm TL) exposed to four treatments of DO: (1) constant normoxia (6.50 +/- 0.50 mg O-2 l(-1)), (2) constant hypoxia(2.79 +/- 0.19 mg O-2 l(-1)). (3) constant intermediate hypoxia (4.74 +/- 0.18 mg O-2 l(-1)). and (4) an oscillating oxygen environment cycling dielly between the normoxic and hypoxic levels (2.8-6.2 mg O-2 l(-1), daily mean = 4.40 mg O-2 l(-1)). Routine respiration was positively correlated with DO level and increased significantly during the day in the oscillating treatment in response to increasing DO. Ventilation rates were negatively correlated with the DO level in the constant treatments and increased significantly at night in the oscillating treatment in response to nocturnal hypoxia. Similarly, hematocrit levels were negatively related to DO levels in the constant treatments after 5 and 26 days of exposure to the treatments. Hematocrit levels also increased significantly the oscillating treatment, apparently in response to the episodic nocturnal hypoxia. Growth was significantly reduced in the 2.8 mg O-2 l(-1) treatment and the oscillating treatment but not in the 4.7 mg O-2 l(-1) treatment. Acclimation was evident by an increase in growth rates from week 2 to week 3 and a decrease in hematocrit levels between 5 and 26 days of exposure in the 2.7 and 4.5 mg O-2 l(-1) treatments but was not evident in the normoxic or oscillating treatments. These results suggest that a juvenile fish must remain in even moderately low DO in order for acclimation to occur. The research presented demonstrates that correctly assessing habitat quality in terms of DO requires knowledge of a fish's physiological and environmental history.

Tyler, R. M. and T. E. Targett (2007). "Juvenile weakfish Cynoscion regalis distribution in relation to diel-cycling dissolved oxygen in an estuarine tributary." Marine Ecology Progress Series **333**: 257-269.

Shallow estuarine waters that serve as nurseries for fishes along the Atlantic and Gulf coasts of the USA can undergo wide diel dissolved oxygen (DO) fluctuations (< 2 to similar to 20 mg O-2 l(-1)) during summer. In this study, the distribution of juvenile weakfish Cynoscion regalis was investigated in relation to diel-cycling DO during summer 2001 in a mesohaline tributary of Indian River Bay, Delaware, USA. Weakfish were collected at 3 sites (upper, middle, and lower) along the similar to 5 km length of Pepper Creek on 15 d using an otter trawl. Near-bottom DO was monitored continuously over the summer, every 15 min, using multi-parameter sondes. Peak abundance of weakfish coincided with the greatest frequency, intensity, and spatial extent of severe diel-cycling hypoxia. events (< 2 mg O-2 l(-1)). Severe hypoxia first occurred in early June in the upper creek and recurred there almost daily for periods of 1 to 4 h until early September. Whenever bottom DO was > 2.0 mg O-2 l(-1), weakfish were more abundant at the

upper site than at the middle and lower sites, which also experienced severe hypoxia but at much lower frequency. However, under all environmental conditions they were absent from the upper site whenever bottom DO was < 2 mg O-2 l(-1), and returned within 2 h of DO exceeding 2 mg O-2 l(-1). Daily up- and down-creek movement occurred over a distance of similar to 1 km. These findings indicate an avoidance threshold of similar to 2.0 mg O-2 l(-1) for juvenile weakfish and demonstrate very temporally dynamic DO-related movement. Their rapid return to these areas as DO conditions improve, and relatively high density in tidal tributary headwaters, suggests that these relatively small areas provide important habitat for fishes.

Wannamaker, C. M. and J. A. Rice (2000). "Effects of hypoxia on movements and behavior of selected estuarine organisms from the southeastern United States." Journal of Experimental Marine Biology and Ecology **249**(2): 145-163.

Hypoxia, or low dissolved oxygen, remains a common occurrence in estuarine waters as human activity in coastal areas expands. Fish kills, probably the most recognized indicator of these and other water quality problems, have significantly increased in recent years in many Southeastern United States estuaries. While entire aquatic communities are impacted by changes in available oxygen, estuarine organisms serve as appropriate indicators of these changes as they exhibit complex physiological and behavioral responses to hypoxia. The consequences of hypoxia for these species depend on their ability to detect and avoid areas of low dissolved oxygen. We conducted a series of two-way, replicated choice experiments with juvenile spot (Leiostomus xanthurus), pinfish (Lagodon rhomboides), croaker (Micropogonias undulatus), menhaden (Brevoortia tyrannus), white mullet (Mugil curema), mummichog (Fundulus heteroclitus), and brown shrimp (Penaeus aztecus) to determine their ability to detect and avoid specific levels of hypoxia. Additional data on organisms' movement patterns, aquatic surface respiration, and ventilation rates were collected. All species tested could detect and avoid 1 mg l(-1) dissolved oxygen. The hypoxia avoidance response differed among species, as some species exhibited an avoidance threshold while others exhibited a graded avoidance response. These data supply baseline information necessary to assess how some mobile estuarine organisms respond behaviorally to oxygen concentrations, and to understand how hypoxia more broadly impacts fish populations and estuarine community health. (C) 2000 Elsevier Science B.V. All rights reserved.

Welker, T. L., et al. (2007). "Effect of sublethal hypoxia on the immune response and susceptibility of channel catfish, Ictalurus punctatus, to enteric septicemia." Journal of the World Aquaculture Society **38**(1): 12-23.

The effect of sublethal hypoxia exposure on stress and immune responses and susceptibility to Edwardsiella ictaluri infection in juvenile channel catfish, Ictalurus punctatus, was investigated. Fish were monitored for temporal changes in glucose and cortisol concentrations before, during, and after 2 h exposure to sublethal hypoxia (< 2 mg/L dissolved oxygen [DO]) and when maintained under normoxic conditions (6.0 +/- 0.3 mg/L DO). Both blood glucose and plasma cortisol increased significantly in response to hypoxic conditions. Fish exposed to hypoxic or normoxic conditions were challenged with a high dose (1.3 x 10(7) colony-forming units [CFU]/mL) or a low dose (1.3 x 10(5) CFU/mL) of E. ictaluri or sterile culture broth by 30-min immersion bath. Approximately 1% of fish in both the normoxic and the hypoxic groups died when challenged with the low dose of E. ictaluri. However, when challenged with the high dose

of E. ictaluri, catfish exposed to hypoxic conditions had significantly higher cumulative mortality (36 +/- 12.1%) than those maintained under normoxic conditions (12 +/- 1.1%). Total hemolytic complement and bactericidal activities and antibody response were lower in hypoxia-exposed channel catfish, indicating that increased susceptibility of channel catfish to E. ictaluri may be the result of the immunosuppressive effects of the stress response to hypoxia.